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TOPIC No. 3: AGRICULTURAL PRACTICES MORE FAVOURABLE TO THE ENVIRONMENT

by

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(Note by the Secretariat)

1. At the Preparatory Meeting for the Sixth Working Conference of Directors of Agricultural Research it was decided that several Member countries would present discussion papers on Topic No. 3 "Agricultural practices more favourable to the environment" of the Conference agenda.

2. The attached report which was prepared by Drs. L. Brussard, H. van Keulen, R. Rabbinge and P. H. Vereijken (Netherlands) is circulated to participants in the Sixth Working Conference of Directors of Agricultural Research for REFERENCE and DISCUSSION.

Agricultural practices more favourable to the environment

by

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I. Integrated production systems (rotations, cultivation methods, cropping patterns

INTRODUCTION

The present situation in the plant production sector requires serious reconsideration of its aims and methods. To solve the complex problems facing the sector it is suggested to develop integrated production systems, considering multiple goals: a market-oriented and efficient production, high quality of the production process and the products, minimum costs of production, minimum effects on the environment and conservation of nature and landscape. This requires research to increase knowledge and insights which help to develop production techniques that as much as possible contribute to realisation of the multiple objectives of integrated agricultural systems.

A FRAMEWORK FOR RESEARCH

The framework for research on the aggregation level of crops and the farm is schematically presented in the following matrix, in which the rows represent the various disciplines and the columns different stages of research.

Matrix describing the framework for research on integrated agricultural systems

	analysis	development and application	optimisation and evaluation
I. Nutrient cycling			
a. soil structure			
b. efficiency of nutrient utilization			
c. soil biology			
d. soil contamination			
II. Pest and disease control			
a. crop health			
b. crop rotation, including green fallow			
c. crop management			
d. yield risks			
III. Weed control			
a. competitive ability of crops			
b. crop management			
c. crop rotation, including green fallow			
d. yield risks at the farm level			
IV. a. yield stability			
b. crop growth			
c. adaptation of crops to environmental conditions			

'Analysis' refers to basic research aiming at increased insight in the processes governing growth and production, with the purpose of integrating this disciplinary knowledge in the design and development of integrated agricultural production systems.
'Development and application' refers to the study of integrated production systems at the farm level. At this level, interactions between the various subsystems have to be studied, and the relevant parameters that characterize the goals that have been formulated, must be defined and determined.
'Optimisation and evaluation' refers to the evaluation of the performance of the integrated production systems, including

assessment of the degree to which the various goals formulated have indeed been attained, assessment of constraints for more complete goal attainment and proposals for adaptation of the production systems to promote goal attainment.

RESEARCH TOPICS

A. Analysis

I. Nutrient cycling

To minimize losses of nutrients to the environment the supply of nutrients, both from natural sources and from amendments (fertilizer, manure) should coincide as much as possible with the demands of the crop, both in space and in time. Therefore, increased insight is necessary in the supply from natural sources (organic matter dynamics, mineralisation, contribution from precipitation) as affected by environmental conditions and crop status. Moreover, we need a better quantitative understanding of the demand of the crop, as affected by environmental conditions and crop development stage and of the processes, determining the fate of amendments (volatilisation, denitrification, immobilisation, leaching, crop uptake). The role of root properties in determining nutrient uptake capacity must be studied, as influenced by soil conditions, especially soil structure.

II. Pest and disease control

An economically effective control of pests and diseases with minimum side-effects on nature and environment requires detailed knowledge of pest and disease development in relation to environmental conditions and crop status, and of the damaging effect (yield losses) of pests and diseases, as related to species and cultivar characteristics (resistance) and environmental conditions. Sampling and monitoring techniques have to be developed that permit rapid and accurate assessment of levels of infestation as an aid in the choice of crop rotation and management techniques.

Methods have to be developed for decision making on biocide application based on economic damage levels. These can be derived from knowledge on pest and disease development as affected by environmental conditions and crop development stage, expected environmental conditions and yield and price expectations. That should lead to a lower and more efficient use of biocides.

III. Weed control

Economically effective and sustainable weed control with minimum environmental side-effects requires detailed knowledge of weed development and of the effects of weed infestation on crop yields in relation to environmental conditions and crop status.
Weed control should aim at minimizing the negative effects of weeds on crop yield and quality, while at the same time minimizing costs and environmental pollution. To achieve that, quantitative insights are necessary in population dynamics and in the relation between level of infestation and yield loss for different crop/weed combinations. In addition, methods should be developed for mechanical, thermic and biological weed control in order to substitute herbicides as much as possible.

IV. Crop management

Most farmers try to achieve a maximum profit by a maximum yield. Moreover, certain quality characteristics are taken into account, either in terms of specific crop components, or of physical or chemical characteristics of the products. The degree of realisation of that aim mainly depends on appropriate management in relation to the choice of cultivar, sowing or planting time and density, fertilizer application, and crop protection. However, the effects of these management aspects are strongly affected by environmental factors that cannot be controlled. To optimize crop management it is necessary to develop advisory systems based on quantitative description of the interactions between environmental factors and crop management. Such advisory systems must aid the farmer in his decision making so that the efficiency of utilisation of inputs in the system is maximized and losses to the environment are minimized.

B. Development and application

I. Arable farming

In the Netherlands integrated production techniques have been developed on an experimental farm at Nagele in the central clay district (Vereijken, 1989). This prototype farming system will be introduced and tested in practice, in cooperation with the extension service. Similar production techniques for other regions, differing in soil conditions and crop rotation must be developed in the short run, possibly in direct cooperation with interested farmers.

II. Outdoor horticulture

This sector is characterized by a great crop diversity, with a strong tendency to regional specialisation. Therefore introduction of integrated production techniques should take place at various locations to cover the main production techniques. The major demands are a strong reduction in the use of biocides, and a more judicious use of chemical fertilizers, with the aim of reducing costs, maintain product quality (residues) and minimize environmental pollution.

III. Fruit production

In such a perennial production system, introduction and testing of integrated systems will take several years. The main issue is to increase stability of the production system. The most promising venues are: introduction of biological pest and disease control to reduce use of biocides, and integrated management measures. Unfortunately very little experience is available at the moment, hence practical introduction may have to be delayed for some time.

IV. Flower bulb production

In this sector the main issue is the abundant use of soil disinfectants, causing important environmental pollution. Again, very little study of lower inputs has been made, hence introduction will have to be preceded by development of experimental integrated systems.

C. Optimisation and evaluation

There is a strong need for comparative analysis of current and integrated production systems, as well as an evaluation of the degree of goal attainment for the various goals in integrated production systems. Models at the farm level could be used to design 'optimum' mixes of production techniques, that contribute as much as possible to the various goals pursued.
On the basis of results of farm models, models at the regional scale should be developed that allow evaluation of the effects of introduction of integrated production techniques for environmental pollution. For that purpose multiple goal linear programming techniques have shown to be a useful tool (Ayyad and Van Keulen, 1987).
An urgent need exists for the development of methodologies that allow evaluation of the effects of the introduction of integrated production techniques. In general paramenters for goal attainment have not been identified, and measurement methods still have to be identified and developed.

PERSPECTIVES AND RECOMMENDATIONS

The Netherlands have been and are foremost in intensifying agriculture and therefore were one of the first countries faced with the side-effects of such a policy. It is not surprising that it is leading the way in the development of alternative farming systems, with the intention to integrate various objectives in terms of economics, employment, environment, nature, landscape, quality of food-stuffs and well-being of man and animal. Although several other OECD countries are planning or starting similar experimental work, it should be stated that research efforts are still far from optimal. Therefore it is strongly recommended to develop national programs in all member countries. Preliminary results of an experimental farm at Nagele, The Netherlands, indicate that considerable savings of pesticides and fertilizers can be achieved along with a better income for the farmers (Vereijken, 1989; Zadoks, 1989).

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II. Sustained agricultural production systems with reduced or better use of agrochemicals and energy (low input agriculture; organic farming)

INTRODUCTION

Simulation models of plant growth as influenced by environmental conditions and pests and diseases have been instrumental in defining conditions for maximum crop production and early prevention or control of pests and diseases. In such simulation models no knowledge of soil processes is needed as the models assume nutrient and water supply to be non-limiting In model descriptions of water and/or nutrient-limited plant growth, the soil is included usually as a black box with rate equations to represent the rooting depth, the transport and uptake of water and nutrients and the dynamics of nutrients. The nutrient balance is described as the result of fertilization/manuring and plant uptake with intermittent adsorption-desorption turnover or

mineralization-immobilization turnover. Although acceptable as a first guess, the models are not yet sufficiently precise. With the current emphasis on reduction of nutrient losses to the environment, and with the current interest in reduced-input agriculture, calling for more efficient resource use, there is a clear need to better describe biotic and abiotic soil processes in the unsaturated zone. Only in that way simulation models of crop growth can be improved around the point where nutrient supply is just enough and, hence, leakage of nutrients to the environment can be prevented.
Improved simulations should guide appropriate measures towards efficient plant production and minimal nutrient losses.

CURRENT STATE OF RESEARCH AND RESEARCH NEEDS

Knowledge needed for economic agricultural production with less pollution and reduced inputs can be derived from research on:

- transport processes in the unsaturated zone
- rhizosphere biology
- decomposition of organic matter and mineralisation of nutrients
- soil structure.

Transport processes in the unsaturated zone

The volume fractions, geometrical structure and composition of the solid, liquid and gaseous phases of the soil characterize the environment for the growth of roots and of soil microflora and fauna, while soil temperature influences their activity. Transport processes of water, gases, solutes and heat govern the spatial and temporal patterns of key factors in the soil environment. In transport processes, roots play a key role as consumers (of water, oxygen, nutrients) or producers (of CO_2, exudates). Water balance models have proved helpful in describing and explaining the transport of water in the soil/plant atmosphere system and will be helpful in the description of the transport of nutrients to the

roots. Recent work has shown that the assumption of a fixed rooting depth and/or activity in such models seriously limits their value. A better description of root development, both in terms of depth and pattern, and of the degree of root-soil contact is one of the most urgent research needs to improve the description of root functioning and the associated availability of water and nutrients to the crop. Concurrently, this facilitates a better description of processes involved in loss to the environment.
Transport of nutrients and contaminants in the soil is strongly coupled to water flow. The dispersion which occurs on a field scale as a result of bypass-flow in macropores and cracks needs to be quantified.

Rhizosphere biology

Root exudates and sloughed-off cells provide energy to the rhizosphere microflora while root symbionts (nitrogen fixing bacteria, mycorrhiza) receive energy directly from the plant. Symbionts may supply the plant with nutrients, whereas the rhizosphere microflora may immobilize nutrients. The rhizosphere fauna, in particular protozoa and nematodes, influences the availability of nutrients for plant uptake by 'grazing' on the rhizosphere microflora. The interaction between processes induced by the plant and by the rhizosphere microflora and -fauna can be studied by labelling the plant and/or rhizosphere microflora with $^{13/14}C$ and/or ^{15}N. Basic research on such interactions is needed for the evaluation of the role of both naturally occurring and introduced organisms in the rhizosphere, whether genetically manipulated or not, in terms of adjusting the N-supply to the plant's needs. Symbionts and free-living microorganisms may help to promote plant growth through the production of plant growth substances. Similar research also helps to evaluate their potential for biological control of soil-borne pests and diseases. Such studies are also needed for the evaluation of crop varieties with different root surface, root exudation, root symbiosis and rooting pattern characteristics.

Decomposition of organic matter and mineralization of nutrients

In addition to the root and root-derived substances, dead organic matter constitutes the most important substrate of biological activity in soil. One of the most important limitations in present simulation models aiming at fertilizer recommendations is insufficient knowledge of factors determining the rate of organic matter decomposition and the associated mineralization of plant nutrients. This lack of knowledge is even more constraining in reduced input agriculture as the lower input of artificial fertilizers increases the importance of mineralization from dead organic material, be it crop residues or manure, for crop nutrient supply. Basic research is therefore required, which can make use of labelled ($^{13/14}C$, ^{15}N) organic substrates. Such research should include investigation of the role of the soil fauna in mineralization processes. The soil fauna has been reported to mediate approximately 30% of the nitrogen mineralization in various (agro)ecosystems by at least three functions: comminution of organic matter (mainly through activity of the macrofauna, i.e. arthropods and earthworms); direct excretion of nitrogen released from ingested microbes (mainly through the activity of the microfauna, i.e. protozoa and nematodes); and stabilization of microbial and microfaunal populations (mainly through the activity of microarthropods, i.e. mites and collembola). Such basic research is needed to evaluate the quality (structural aspects; C:N ratio), and amounts of organic matter to be added and the timing of its addition. Soil tillage operations probably are the major factor determining the location of organic additions (crop residues, manures) to the soil. Therefore the evaluation of the effects of the placement of organic additions on subsequent biological processes is needed.

Soil structure

The spatial arrangement of soil particles determines both abiotic soil properties (such as characteristics for retention and transport of water and heat, for diffusion of gases, and for transport of solutes) and biological phenomena (such as root penetration, movement of animals, occurrence and rates of biological processes, e.g. denitrification). In their turn abiotic processes (such as shrink-swell, drying-rewetting) and biological phenomena (root penetration, burrowing by the fauna, defecation by the fauna) determine soil structure. Soil tillage therefore drastically affects interactions among and between biotic and abiotic processes. Basic knowledge is required on physical and biological agents that reorganize soil structure to redistribute substrates and organisms in order to evaluate the optimum degree and timing of soil tillage and the placement of crop residues and other organic additions to the soil.

SYNTHESIS OF RESEARCH RECOMMENDATIONS

The research topics advocated are summarized in table 1, together with the objectives at which they are aimed. Research programs should be developed on the basis of existing and improved models of crop growth, soil physical and soil biological processes. Models will be developed through the iterative process of hypothesizing and testing on the basis of experimental data.
The prioritary research topics recommended, are derived from the following considerations :

* that the main option for the management of biological resources is changes in farm management (crop varieties; timing, placement, quality and quantity of organic additions; amount, placement and timing of fertilization; timing, extent and kind of soil tillage; addition of organisms in biological or integrated control);

* that studies of nutrient transformations and of the survival of naturally occurring or introduced organisms, either genetically transformed or not, need to acknowledge the effects of soil structure on the organisms involved and on their abiotic environment;
* that studies of soil physical processes and soil structure need to acknowledge the effects of the soil biota involved and the energy and nutrients they need for their activity;
* that the research topics recommended are necessary to improve the management of the soil biota as part of the management of biological resources in sustained agricultural production systems;
* that improvement and coupling of models on crop growth, soil transport processes, and soil organic matter transformations is necessary and possible.

Table 1. Summary of research recommendations and their objectives.

Research area	Research topic	Objective
Transport processes in the unsaturated soil	Description of root development (depth, pattern, activity) and degree of root-soil contact Bypass-flow in macropores and cracks	To predict amounts of water and nutrients available for uptake by plant or loss to environment
Rhizosphere biology	Quantitative description of root- microflora-fauna-interactions	To evaluate potential of naturally occurring and introduced (genetically transformed) soil organisms for plant growth promotion and biological control. To evaluate rhizosphere effects of different crop varieties.
Decomposition of organic matter and mineralisation of nutrients	Quantitative description of the biological turnover of dead organic matter, in particular the role of the soil fauna	To optimize the quality, amount and timing of organic additions to the soil.
Soil structure	Interactions among and between biotic and abiotic factors determining soil structure	To optimize the degree and timing of soil tillage and the placement of organic additions to the soil